1981-22

VOYAGER 2 REPROGRAMMED FOR NEW OBSERVATIONS AT SATURN

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Accepted for Publication in
NATURE, News and Views Section, August 20, 1981

SRL 81-22
July, 1981

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In the last two years, the Pioneer 11[1,2] and the Voyager 1[3,4] encounters with Saturn have revealed a remarkable richness and diversity of physical phenomena. As a result of these discoveries and of continued earth-based studies, major changes have been made in the observations planned for Voyager 2, providing additional opportunities for discovery and understanding of the Saturn system. These opportunities are further enhanced by the significantly different path that Voyager 2 must take through the system, passing 101,000 km above Saturn's cloud tops on August 26 as it continues on to Uranus. Although the most exciting discovery may be completely unexpected, some of the opportunities for new observations are described below for each of the four major areas of investigation — the atmosphere, the rings, the satellites, and the magnetosphere.

The study of the dynamics of Saturn's atmosphere is of interest because Saturn, like Jupiter, is a giant, rapidly rotating body composed mainly of hydrogen and helium, encircled by bands of clouds of frozen ammonia with large-scale wind patterns distinctly different than that of the Earth's atmosphere. On Jupiter, opposing eastward and westward jet streams are at the edges of adjacent cloud bands, with a maximum eastward equatorial velocity of ~ 450 km/h. At Saturn, Voyager 1 found equatorial winds 4 times faster and found that the pattern of opposing jet streams occurred only above $\sim 35°$ latitude. Voyager 2 will not only make a month-long time lapse movie of the wind patterns, but will also provide a high resolution view of the pattern of opposing jet streams in the north polar region. The winds in the atmosphere above the clouds exhibit a different pattern which will be determined from a high resolution thermal map of the upper atmosphere. Other studies include a deep probing of the temperature and pressure of the atmosphere by the radio beam as the spacecraft disappears behind the planet, where images of the dark side of Saturn will be taken to search for lightning. Since Voyager 1 discovered ultraviolet auroral emissions at 80° latitude and similar emissions near the equator, Voyager 2 will also perform a systematic latitude search for such emissions.

The rings, the second major area of study, presented the most surprises from Voyager 1, and the Voyager 2 observations have, as a result, been almost completely revised and enlarged. The Voyager 2 observations will be further enhanced by the increased solar illumination of the north face of the rings as the Saturn year continues toward northern summer and by a much closer approach to the rings than on Voyager 1. Unlike both Voyager 1 and Pioneer 11, Voyager 2 will view the lighted face of the rings at closest approach.

Among the Voyager 1 discoveries was that the bright, broad B-ring appears to consist of hundreds of ringlets separated by narrow gaps, each one of which may be cleared by small, kilometer-sized satellites. The Voyager 2 photopolarimeter will observe the star Delta Scorpii through the shadowed region of the rings for 2 hours and 18 minutes, during which time the star will move radially outward behind the rings, its apparent intensity varying as it moves from behind a ringlet into the adjacent gap. This stellar occultation should determine the location, width, and spacing of the ringlets with a precision of 100 to 300 meters. A second, shorter stellar occultation observation of Beta Tauri will provide 5 times more precise measurements of the braided F-ring and the outer edge of the main ring system. Near closest approach, the highest resolution images should reveal any structure down to the subkilometer scale.

The dynamics of the braided F-ring will be studied with a sequence of observations keyed to assessing the importance of various physical processes in its formation. The fine submicron-sized material in the braids is radially confined by two shepherding satellites (1980S26 and 1980S27) on either side of the F-ring. Images of the F-ring near these two satellites may indicate whether they are perturbing the motion of the ring particles in such a way as to cause the braided appearance, while repetitive images of the ring should indicate whether the braided structure is stable or varies on a short time scale. Images of the portion of the ring emerging from Saturn's shadow may provide clues to the influence that electrostatic charging of the small ring particles may have on the braided structure, since the electrostatic charge on the particles will likely change with the cessation of photoelectron emission normally occurring in sunlight.

The "spokes" in the B-ring are also currently not understood, although they appear to form sporadically in Saturn's shadow and almost dissipate before completion of a single orbit about Saturn. Like the F-ring braids, the spokes consist of fine particles, possibly elevated in a cloud above the ring plane. As Voyager 2 crosses the ring plane, 3 images will be taken of the rings edge-on, in a search for any elevated material. Prior to closest approach, a 13.5 hour-long time lapse movie will be taken to study the dynamical properties of individual spokes as they are distorted by the greater angular velocity of the spoke material nearer Saturn.

The closer approach to the rings also provides for further study of the electrostatic discharges detected by Voyager 1. Although the origin of the discharges has not been directly determined, they occur episodically every 10h 10m, leading to the suggestion that the discharges may be associated with a satellite with this orbital period imbedded within the B-ring. Additional high time-resolution samples of electromagnetic wave activity will be acquired over the 10 Hz to 40 MHz frequency range, including one when the spacecraft crosses the ring plane.

Another major area of study is the Saturnian satellites, of which seventeen are currently known. Of these, only Titan is a major satellite, similar in size to the planet Mercury. Titan, with a dense atmosphere including nitrogen and methane in which organic photochemistry is occurring, was a primary target for Voyager 1. Voyager 2 will observe Titan from a much greater distance (see Table 1), returning information on the light scattering properties of the photochemical haze and possibly on the winds.

Seven of the satellites are intermediate in size, composed mainly of water ice, with diameters ranging from about 300 to 1500 kilometers. Of these, Voyager 1 observed Mimas, Dione, and Rhea with high enough resolution to disclose that their icy surfaces are heavily cratered from impacts, as was expected. Unexpected, however, were regional systems of fractures and sparsely cratered plains which are evidence of significant crustal evolution. Voyager 2 will extend the high resolution coverage to Tethys, which has a $\sim$ 750 km long valley, and to Enceladus, which is highly reflective and appears to be relatively devoid of impact craters. The absence of craters on Enceladus would require a source of energy large enough to cause significant modification of the surface. In order to investigate Enceladus' thermal properties, the rate of cooling of the satellite as it moves into Saturn's shadow will be determined from infrared temperature measurements.

Less is known about Hyperion and Iapetus, the other two intermediate satellites. Voyager 2 will fly closer to both than did Voyager 1, returning images with enough resolution to determine if there are large valleys as on Tethys or if there is other evidence of crustal evolution.

As indicated in Table 1, there are at least nine other smaller satellites with estimated diameters ranging from about 30 to 220 km. Voyager 1 determined approximate shapes for only 1980S28, which is just outside of the main rings, and the two satellites which share essentially a common orbit, 1980S1 and 1980S3. All three were found to be distinctly non-spherical. Voyager 2 will determine the shape of all of the remaining known satellites, including the F-ring shepherding satellites (1980S26 and 1980S27), the two satellites recently discovered in ground based images[5] which share a common orbit with Tethys (1980S13 and 1980S25), and 1980S6 which shares an orbit with Dione. There will also be a search for new satellites, both outside of and imbedded within the ring system. Photometrically accurate measurements of the amount and the degree of polarization of light scattered from the different satellites will provide additional information on the texture and gross composition of their surfaces.

The fourth major area of study is that of the planetary magnetic field, plasma, trapped energetic particles, and wave emissions comprising Saturn's magnetosphere. Periodic bursts of radio emissions in the 100 kHz to 500 kHz frequency range provided the first accurate determination of the period of rotation of Saturn's magnetic field which is believed to be the period of rotation of Saturn's interior regions where the magnetic field originates. This period, which is 10h 39.4m, will be more accurately determined with the longer time base provided by Voyager 2, while measurements of Saturn's magnetic field may identify the longitudinal asymmetry resulting in the localization of the radio emission to specific Saturnian longitudes. Voyager 2 will also provide additional observations of the 2.7-day modulation of the radio emissions thought possibly to result from Dione's interaction with the magnetosphere.

The effects of Mimas and Enceladus on the magnetosphere will be directly measured as Voyager 2 passes just inside Mimas' orbit. Measurements deep within the magnetosphere will better define the structure of the equatorial disk of plasma and the extent to which the icy satellites are sources or absorbers of magnetospheric particles. From Voyager 1, it is known that Titan's atmosphere is the source of at least some of the particles.

Voyager 2 may also provide the rare opportunity for observing the effects of Jupiter's magnetotail on Saturn's magnetosphere. There is recent evidence from Voyager 2 that Jupiter's magnetotail, which may resemble a tattered wind sock flapping in the solar wind, extends at least 4.5×10^8 km outward from Jupiter. Since during the last few months Saturn has been almost radially aligned with Jupiter, it is likely that Saturn has been occasionally immersed in the extended Jovian magnetotail. Such an immersion could at least temporarily result in variations in the size, shape, and other characteristics of Saturn's magnetosphere, leading to the possibility that there may be significant differences between the Voyager 2 observations and those of Pioneer 11 and Voyager 1.

Intensive observations of the Saturnian system, which began June 5, will continue until September 28, at which time Voyager 2 will return to the cruise mode and, like Voyager 1, continue exploring the interplanetary medium at increasing distances from the sun. In late 1985, Voyager 2 will return to the encounter mode as it approaches a flyby of Uranus on January 24, 1986, and heads toward an encounter with Neptune on August 24, 1989. Beyond Neptune, both spacecraft will continue exploring the outer limits of the region dominated by the solar wind, where low energy galactic cosmic rays may be first observed and beyond which lies the interstellar medium. Thus, there is the potential for continued significant scientific return from the Voyager spacecraft well beyond that originally planned for the mission to Jupiter and Saturn.

1. Science 207, 400-453, 1980.

2. J. geophys. Res. 85, 5651-5958, 1980.

3. Science 212, 159-243, 1981.

4. Nature, this issue.

5. Seidelmann, P.K., et al. Preprint (1981); Veillet, C. IAU Circ. Nos. 3593 and 3608 (1981); Larson, S.M. Icarus in press (1981).

Table 1 Voyager 2 closest approach distances to Saturn's satellites (August 23 through 26, 1981)

Name	Diameter (km)	Orbital radius (R_S)*	Closest approach** distance (km)
1980S28	40 x 20	2.28	287,170
1980S27	220	2.31	246,590
1980S26	200	2.35	107,000
1980S3	90 x 40	2.51	147,010
1980S1	100 x 90	2.51	222,760
Mimas	390	3.08	309,990
Enceladus	500	3.95	87,140
1980S25	30 - 40	4.88	284,400
Tethys	1,050	4.88	93,000
1980S13	30 - 40	4.88	153,520
1980S6	~ 160	6.26	318,200
Dione	1,120	6.26	502,250
Rhea	1,530	8.74	645,280
Titan	5,140	20.25	665,960
Hyperion	290	24.6	470,840
Iapetus	1,140	59	909,070
Phoebe	~ 160	215	2,075,640

* Mean distance of the satellite from the center of Saturn in units of Saturn radii (1 R_S = 60,330 km).

** From a distance of 100,000 km, the geometrical resolution of the imaging system is 2 km/line pair.